The effects of linear infrastructure and other anthropogenic disturbance on aquatic ecosystem, in particular on freshwater macroinvertebrates

Thesis booklet

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Introduction

About 2500 years ago the Greek philosopher Heraclitus presented an analogy regarding the dynamic flux of human life: "You cannot step twice into the same river". To stream ecologists this phrase has literal truth; spatial and temporal changes in lotic systems provide a shifting mosaic of abiotic and biotic conditions. An obvious source of this variability is the disturbance caused by rapid increases (as in spates) in the volume of water passing a point in time and the accompanying movements of substratum that result from high discharge. However, prolonged low discharge (as in droughts) and anthropogenic factors may also act as disturbances (Resh et al., 1988). Water is widely regarded as the most essential of natural resources, yet freshwater systems are directly threatened by human activities (Vörösmarty et al., 2010). Disturbance is any relatively discrete event in time that disrupts ecosystem, community, or population structure, and that changes resources, availability of substratum, or the physical and chemical environment (Resh et al., 1988). Urban development affects the habitat, geomorphology, and the quantity and quality of water in downstream ecosystems by altering hydrology and increasing the delivery of nutrients, sediments, metals, and other pollutants. These changes in habitat, flow regimes, and stressors negatively affect ecosystem services and the structure and function of aquatic communities, from microbial processes, to algae, macroinvertebrates, and fish (Meyer et al., 2005; Walsh et al., 2005; Smucker & Detenbeck, 2014). Macroinvertebrates play an important role in freshwater ecosystems by feeding on various food resources (e.g. algae, coarse detritus or fine particulate organic matter) (Rosenberg & Resh, 1993), by ecosystem engineering (Mermillod-Blondin, 2011), as well as by providing food for higher trophic levels (Covich et al., 1999). Therefore, macroinvertebrates contribute to several ecosystem services as herbivores, predators or detritivores. Freshwater macroinvertebrate communities are widely used in biomonitoring and bioassessment because they show predictable responses to water and habitat quality (Zhang et al., 2013).

The anthropogenic disturbances as a widespread and ever-increasing phenomenon involving urbanization, agriculture, pasture conversion, deforestation, and the replacement of native species by exotic ones with commercial value (Allan, 2004; Miserendino et al., 2011). Represents a real and pervasive threat to the biodiversity and conservation of lotic ecosystems thus their research are necessary. In order to be able to track anthropogenic impacts on a river section, or even across a river basin, we need to develop new methods and tools.

Objectives

The dissertation covers four major topics that examine the effects of anthropogenic effects and disturbances on the aquatic ecosystem. The first study provides an overview about the effects of urbanization on freshwater macroinvertebrates, while the other two deal with specific and very current ecological problems and the fourth is about developing a method that contributes to ecological studies of anthropogenic effects.

1. The objective was to assess the effect of urbanization on freshwater macroinvertebrate diversity. To address this issue, we performed a systematic review along with a meta-analysis. We focused on the following questions: (I) Which taxonomic groups have been examined when studying the effect of urbanization on macroinvertebrate diversity? (II) How is diversity conceptualized (i.e. which diversity facets and components are the foci in a study) and measured in these studies? (III) Which habitat types are examined? (IV) Does urbanization influence, in general, the diversity of freshwater macroinvertebrates? Our aim with the identification of knowledge gaps to make recommendations for future research.
2. Our objective was to examine the effects of road crossings on the diversity of stream macroinvertebrates. In particular, we asked (I) whether the abiotic habitat at road crossings is different from the unaltered upstream and downstream sections, (II) whether the road crossings decrease the diversity of native macroinvertebrates, (III) whether the road crossings attract more alien taxa than the unaltered stream sections, and (IV) whether the road crossings alter the community composition of macroinvertebrates.
3. Our objective was to present a list of species of ornamental freshwater decapod crustaceans pet-traded in Hungary and their risk assessment, including the probability of establishment based on climate matching. Further aim was to DNA identification of the new decapods that we found during the field sampling.
4. Our aim was to develop an index designed to incorporate in each point of the river network the various environmental influences of the basin ascribed to it, in order to estimate the quality of freshwaters. The reliability of the index was tested with the aid of in situ measurements of chemical and biological water quality obtained from several sources in Danube basin (Romania and Hungary). Further, our aim was to develop a Python based GIS tool that can automate the computation of the index.

Methods

1. The effect of urbanization on freshwater macroinvertebrates

Meta-analysis: meta-analysis allows the quantitative analysis and summary of the results of several independent studies examining the same question. In meta-analysis, the magnitude of effects (effect size) is quantified from each individual study, and these are then used to calculate the combined (overall) magnitude and significance of the effect under the meta-analytical study.

2. The effects of road crossings on stream macroinvertebrate diversity

Sampling: We selected 9 study sites where a road crosses a stream. Within each site (e.g. Suppl. Fig. 1), we defined a road crossing section located directly below the bridge and two 50-meter long sections, one upstream and one downstream. Kick and sweep sampling techniques were used to collect macroinvertebrates using a hand net (500 μm mesh). At each section (upstream, road, downstream) and sampling date (October 2016, April 2017 and July 2017), we took 3 replicate three-minute samples covering most microhabitats present in the section. The assessment of environmental variables was performed in each stream section. Water chemistry parameters e.g. temperature, pH, conductivity (μS/cm corrected to 25 °C) and salinity (ppt-parts per thousand) were measured with a Hanna Combo pH/EC/TDS/Temp tester (HI 98129 model). Stream sections were also characterized by nine visually estimated environmental variables considering water depth, current velocity and substrate composition.

Identification of macroinvertebrates: Samples were kept separately and preserved in 70% ethanol, returned to the laboratory on the same day and identified to the possible lowest taxonomic level (usually species) according to the relevant references.

Data Analysis*:* Statistical analyses were performed in R (R Core Team, 2016) using the *car, multcomp, MuMIn* and *vegan* packages.

3. Risk assessment of pet-traded decapod crustaceans in Hungary

Data collection: Information about decapod species within the pet trade, their availability, and origin in the Hungarian market was collected from March 2015 to October 2016. Interviews were conducted with 6 wholesalers, 76 pet shop owners, 13 online shops, and 23 local producers. Furthermore, 4 pet bazaars (places where people can privately sell or change pet animals) were also visited.

Climate match for the species found to be pet-traded in Hungary: The climate match between source and target area was compared using the CliClimatch tool (v.1.0; Invasive Animals

Cooperative Research Centre, Bureau of Rural Sciences, Australia, http://data.daff.gov.au:8080/Climatch/climatch.jsp).

Risk assessment: To evaluate the invasive potential of decapod crustaceans pet-traded in Hungary, we used the Freshwater Invertebrate Invasiveness Scoring Kit produced by the UK Centre for Environment, Fisheries & Aquaculture Science

Field sampling: We sampled 1 kmlong section of each selected waterbody using five baited traps set every two weeks from spring to autumn. Thermal localities were additionally monitored during the winter. The traps were exposed and checked for two consecutive days.

Genetic analysis: The morphological identification of each captured specimen was confirmed by a polymerase chain reaction (PCR) of a selected gene (mitochondrial cytochrome oxidase subunit I – COI), utilizing universal primer pair LCO1490 and HCO2198. The samples were sequenced usingthe Macrogen sequencing service in the Netherlands (www.macrogen.com).

4. Integrating catchment land cover data to remotely assess freshwater quality

Land cover data: The 44 classes of the third level of CORINE Land Cover 2012, Version 18.5.1 (available on: http://land.coper nicus .eu) were regrouped into 4 classes based on their anthropogenic potential impact as follows. We defined an index hereafter named "RWQ" (Remote Water Quality) computed as the average of class scores weighted by their respective areas in the catchment of each river network cell.

Conceptual model and its implementation: *RIVERenhancer* is designed to acquire data from vector and raster files, transpose them into hydrological networks, and aggregate into numerical indices by which one can study various characteristics of freshwater habitats. *RIVERenhancer* requires a DEM and a file of geospatial data (e.g., land cover). Using the DEM, it automatically calculates the flow direction and flow accumulation based on which the river network and the watersheds are obtained. For each pixel from the river netwok, the final index value is calculated using the values obtained from the spatial intersection between the watershed and the *CORINE land cover layer*. *RIVERenhancer* was developed using Python (https ://www.pytho n.org), GDAL (http://www.gdal.org), Numpy (http://www.numpy .org) and ArcPy (http://pro.arcgis.com/en/pro-app/arcpy) libraries. The tool is available under MIT license and it can be freely accessed at https ://githu b.com/sandricionut/RIVER enhancer.

In situ water quality database: Data were collected in the field by investigation of randomly selected river sectors across the Romanian Carpathians during the summer season (June to August) of three years (2010–2012) from 405 rivers and streams. Each of the examined sites consisted of sampling for physico-chemical water quality assessment, and in 275 of them, macrozoobenthos was collected for biological water quality assessments.

Physico-chemical assessment: In order to designate water classes, six physico-chemical parameters were used for every site: the pH, dissolved oxygen, dissolved inorganic nitrogen forms (N-nitrate, N-nitrite and N-ammonia) and soluble reactive phosphorus (SRP). These variables were recorded with Hach-Lange multiparameter and spectrophotometer field equipment (Hach- Lange GmbH, Düsseldorf, Germany) following standard procedures. The average of measured values per site was attributed to one of five classes according to Water Framework Directive (WFD) guidelines. After that we defined the final chemical water quality index of a sampling site, hereafter called “CWQ” *Chemical Water Quality*.

Biological assessment: Semi-quantitative samples of benthic macroinvertebrates were collected using the kick-net method in a defined period of 5 min, aiming to be as representative as possible of the diversity of existing microhabitats. The biological quality of water was investigated using the Biological Index of Water Quality defined by Herbst *et al.*, 2001, hereafter denoted “BWQ”.

***Data processing and statistical analysis*:** The analysis of the relation between BWQ and RWQ was performed using the *quantreg* package in R. The analysis of the relationship between CWQ and RWQ was used the R package *nonbinROC.*

Validation of RWQ: Three separate datasets were used for validation. The first dataset contained biological water quality data from 37 sampling sites analysed in the papers of Momeu *et al*., 2009; Cîmpean, 2011; Ivașcu *et al.*, 2013. The second dataset was obtained upon request from the National Administration of Romanian Waters. The third dataset comprised chemical assessments of water quality obtained from Hungarian General Directorate of Water Management. Given that all these indices were of ordinal type, their relationship with RWQ was assessed using Spearman correlation coefficients.

Theses

1. Our research reports the first evidence-based synthesis on urbanization influences negatively the diversity of freshwater macroinvertebrates.
2. We identified knowledge gaps regarding case studies reporting the effects of urbanization on pond and lake ecosystems, case studies examining the phylogenetic and functional facets of biodiversity, as well case studies investigating the effect of urbanization on the beta diversity component of macroinvertebrate communities. The identification of these knowledge gaps allowed us to make recommendations for future research.
3. We found that road crossings had negative effects on the richness and abundance of native macroinvertebrates, as well as on the number of protected taxa.
4. Our results showed also that alien individuals were more abundant at road crossings. These findings support the assumption that road crossings contribute to the spread of alien species.
5. The assessment of environmental variables indicated that road crossings caused habitat modifications.
6. Three crayfish, *Cherax destructor*, *Procambarus clarkii*, *P. virginalis*, and one crab, *Eriocheir sinensis*, were classified in the high-risk category.
7. During field sampling, we found three individuals of *C. quadricarinatus* that were probably released or escaped from aquaria. These are the first records of this species in the wild of Carpathian Basin.
8. We defined a remote measure of the potential of pollution named RWQ (Remote Water Quality).
9. We developed *RIVERenhancer*, a free Python-based ArcGIS tool that can automate the computation of the index.

Publication related to PhD Thesis

B. Gál, I. Szivák, J. Heino, D. Schmera (2019) The effect of urbanization on freshwater macroinvertebrates - Knowledge gaps and future research directions. *Ecological Indicators,* 104: 357-364.

I. Şandric, A. Satmari, C. Zaharia, M. Petrovici, M. Cimpean, K.-P. Battes, D.-C. David, O. Pacioglu, A. Weiperth, **B. Gál**, M. Pirvu, H. Muntean, A. Spataru, M. Neagul, C. Toma, L. Parvulescu (2019) Integrating catchment land cover data to remotely assess freshwater quality: A step forward in heterogeneity analysis of river networks. *Aquatic Sciences* 81: 26.

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Other publication

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